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ORIGINAL ARTICLE

A critical threshold for global pediatric surgical workforce density

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Abstract

Purpose 1.7 billion children lack access to surgical care, particularly in low- and middle-income countries (LMIC). The pediatric surgical workforce density (PSWD), an indicator of surgical access, correlates with survival of complex pediatric surgical problems. To determine if PSWD also correlates with population-level health outcomes for children, we compared PSWD with pediatric-specific mortality rates and determined the PSWD associated with improved survival.

Methods Using medical licensing registries, pediatric surgeons practicing in 26 countries between 2015 and 2019 were identified. Countries' PSWD was calculated as the ratio of pediatric surgeons per 100,000 children. The correlation between neonatal, infant and under 5 mortality rates and PSWD was assessed using Spearman's correlations and piecewise linear regression models.

Results Four LIC, eight L-MIC, ten UMIC and four HIC countries, containing 420 million children, were analyzed. The median PSWD by income group was 0.03 (LIC), 0.12 (L-MIC), 1.34 (UMIC) and 2.13 (HIC). PSWD strongly correlated with neonatal (0.78, $p < 0.001$), infant (0.82, $p < 0.001$) and under 5 (0.83, $p < 0.001$) mortality rates. Survival improved with increasing PSWD to a threshold of 0.37.

Conclusion PSWD correlates with pediatric population mortality rates, with significant improvements in survival with PSWD > 0.37. Currently, PSWD in LMICs is inadequate to meet UN Sustainable Development Goal 3.2 for child mortality.

Keywords Workforce density · Pediatric surgery · Childhood mortality · National surgical planning

Introduction

Despite major improvements in childhood survival in low- and middle-income countries (LMICs), the 2015 Millennium Developmental Goals for neonatal, infant, and child mortality were not met, thus prompting inclusion in the United Nation's Sustainable Developmental Goal (SDG) 3.2: to end preventable deaths of children under 5 years of age by 2030 [1]. Surgery is now unanimously recognized as an essential component of universal health coverage by the 2015 World Health Assembly; access to pediatric surgical services, specifically, is critical to effectively care for congenital conditions and trauma, which disproportionately affect children in LMICs and contribute to preventable morbidity and mortality [2, 3]. With nearly one-fifth of surgical disability-adjusted life-years (DALYs) caused by congenital or perinatal conditions and the known lack of surgical access in LMICs, access to pediatric surgical care remains paramount [4]. However, an estimated 1.7 billion children worldwide lack access to surgical care, including 1.1 billion in low- and middle-income countries (LMICs) where children comprise nearly 50% of the population [5, 6].

Among other indicators of surgical access, the Lancet Commission on Global Surgery (LCoGS) identified the density of surgical providers as a marker of sufficient workforce capacity [7]. The LCoGS demonstrated a strong correlation between surgical workforce density and adult population health outcomes, specifically maternal mortality rate, with a critical threshold of 20 surgical providers per 100,000 people correlating with significant reductions in mortality [7]. This threshold has served as a benchmark

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for surgical access and a target for national surgical planning for scale-up of the surgical workforce in LMICs. While it is well recognized that specific pediatric surgery workforce goals are needed for national strategic planning to improve pediatric care, none currently exist [5, 8].

Specialist pediatric surgeons are needed for treatment of congenital and complex pediatric problems, thus the pediatric surgical workforce density (PSWD) is an important indicator of access to comprehensive pediatric care [9]. Outcomes for specific pediatric surgical conditions in LMICs correlate with PSWD as evidenced by a recent systematic review demonstrating that a PSWD of 0.4 per 100,000 children significantly correlated with increased odds of survival in gastroschisis, esophageal atresia, intestinal atresia, and typhoid perforation [9].

While it makes sense that outcomes from surgical conditions correlate with PSWD, it is unknown if PSWD correlates with pediatric-specific population mortality rates. Therefore, we aimed (1) to assess for a correlation between PSWD and neonatal, infant, and under 5 childhood mortality rates and (2) to identify the critical PSWD threshold associated with significant mortality reduction for national strategic surgical planning.

Methods

Study design and data sources

We conducted a retrospective, cross-sectional study of pediatric surgeons' workforce density (PSWD) using publicly available medical licensing registries and the WHO Global Surgical Workforce Database [10]. Only countries with publicly available data on the subspecialty classification of physicians were included. A convenience sample of 26 geographically and economically diverse countries between 2015 and 2018 was identified.

Countries included in the analysis were classified by the World Bank income brackets including low income (LIC), lower-middle income (L-MIC), upper-middle income (UMIC) and high income (HIC). For each country, the most recent publicly available medical licensing data were used to identify the number of practicing pediatric surgeons with an active license. Pediatric surgeons were defined by country-specific certification as specialist pediatric surgeons.

Given most countries define pediatric care as care delivered to patients less than 15 years old, each country's population less than 15 years old was retrieved from the World Bank [6, 9]. Additionally, the under 5-year old, infant and neonatal mortality rates for each country were obtained [6].

Outcomes and analysis

The primary outcome was each country's respective PSWD, calculated as the number of pediatric surgeons per 100,000 children less than 15 years old. Then for each income bracket, the median PSWD and mean proportion of less than 15-year-old population were determined. The under 5, infant, and neonatal mortality rates were converted to survival rates (1—mortality rate) [9]. Next, the logarithmic under 5, infant and neonatal survival rates were plotted as a function of PSWD [7]. Spearman's correlation coefficients were then used to assess the strength of correlation for each survival rate, using an alpha level of 0.05 to determine significance. Finally, following the LCoGS's methodology, piecewise linear regression models were used to determine the critical PSWD threshold, or inflection point, at which there was a significant increase in survival [7].

Results

A convenience sample of 26 countries was identified: four LIC, eight L-MIC, ten UMIC and four HIC countries, comprising 420,764,643 children (Table 1). The mean proportion of the population less than 15 years old decreased with rise in World Bank income bracket, with 42.8% for LICs, 38.2% for L-MICs, 21.6% for UMICs, and 18.7% for HICs. In LIC countries, the PSWD ranged from 0.02 to 0.24, median 0.03. For L-MICs, the PSWD ranged from 0.03 to 0.36, median 0.12. For UMICs, the PSWD ranged from 0.27 to 7.14, median 1.34. Finally, in HICs, the PSWD ranged from 1.15 to 3.60, median 2.13.

PSWD correlation with pediatric-specific mortality rates

For under 5-years old, infant, and neonatal mortality rates, there was an observed positive correlation between survival rates and PSWD. Countries with higher PSWD demonstrated improved survival rates for each age group (Fig. 1). Furthermore, each survival rate strongly correlated with PSWD: under 5-years old (0.83, $p < 0.001$), infant (0.82, $p < 0.001$) and neonatal (0.78, $p < 0.003$) (Table 2).

A critical threshold of 0.37 PSWD correlated with significant increases in survival, beyond which gains were observed, but the gradient of the curve was flatter (Fig. 1, Table 2). All four LICs, all eight L-MICs and one UMIC were below the critical threshold of 0.37 PSWD. The LIC and L-MICs also reported a higher proportion of their populations aged less than 15 years old (42.8% and 38.2%, respectively). Combined, the number of children in countries

Table 1 Country-specific characteristics including World Bank income bracket, pediatric population (< 15 years old), survival rates, number of pediatric surgeons and calculated PSWD

Country	Income Bracket	Population	% Population < 15 yo	Population < 15 yo	2018 Pop Density per 100,000 (< 15 yo)	Child < 5 mortality (per 1000 live births)	Mean % Population < 15 yo	Child < 5 Survival Rate	Infant < 1 mortality (per 1000 live births)	Infant Survival Rate	Neonatal mortality (per 1000 live births)	Neonatal Survival Rate	Pediatric Surgeons	PSWD per 100,000 children	Median PSWD
Sierra Leone	LIC	7,650,000	0.411	3,144,150	31.4	105		895	79	921	33	967	1	0.0318051	
Uganda	LIC	42,720,000	0.469	20,035,680	200.4	46		954	34	966	20	980	4	0.01996438	
Rwanda	LIC	12,300,000	0.4	4,920,000	49.2	35		965	27	973	16	984	1	0.0203252	
Senegal	LIC	14,578,460	0.43	6,268,738	62.7	50	42.8%	950	35	965	23	977	15	0.23928262	0.03
Zimbabwe	LMIC	14,400,000	0.424	6,105,600	61.1	46		954	34	966	21	979	2	0.03275681	
Kenya	LMIC	51,390,000	0.398	20,453,220	204.5	41		959	31	969	20	980	11	0.05378126	
Nigeria	LMIC	195,900,000	0.439	86,000,100	860.0	120		880	76	924	36	964	110	0.12790683	
Pakistan	LMIC	212,200,000	0.353	74,906,600	749.1	69		931	57	943	42	958	170	0.22694929	
Ghana	LMIC	27,849,219	0.38	10,582,703	105.8	55		945	39	961	26	974	11	0.1039432	
Guinea	LMIC	11,432,090	0.45	5,144,441	51.4	107		893	69	931	33	967	5	0.0971923	
Bangladesh	LMIC	156,256,280	0.29	45,314,321	453.1	36		964	30	970	21	979	161	0.35529606	
Philippines	LMIC	102,113,210	0.32	32,676,227	326.8	30	38.2%	970	24	976	14	986	46	0.14077513	0.12
Colombia	UMIC	49,650,000	0.237	11,767,050	117.7	14		986	12	988	8	992	46	0.39092211	
South Africa	UMIC	57,780,000	0.291	16,813,980	168.1	34		966	29	971	11	989	46	0.27358186	
Peru	UMIC	31,990,000	0.258	8,253,420	82.5	14		986	11	989	7	993	102	1.23585132	
Malaysia	UMIC	31,530,000	0.24	7,567,200	75.7	8		992	7	993	4	996	45	0.59467174	
Mauritius	UMIC	1,265,000	0.178	225,170	2.3	16		984	14	986	9	991	3	1.33232669	
Maldives	UMIC	515,696	0.201	103,655	1.0	9		991	7	993	5	995	3	2.89421929	
Bulgaria	UMIC	7,025,037	0.15	1,053,756	10.5	7		993	6	994	4	996	54	5.12452817	
Costa Rica	UMIC	4,999,411	0.21	1,049,876	10.5	9		991	8	992	6	994	75	7.14369867	
Brazil	UMIC	209,469,333	0.21	43,988,560	439.9	14		986	13	987	8	992	1225	2.78481497	
Thailand	UMIC	68,714,511	0.18	12,368,612	123.7	11	21.6%	989	9	991	6	994	166	1.34210694	1.34
New Zealand	HIC	4,886,000	0.196	957,656	9.6	6		994	5	995	4	996	24	2.50611911	
Trinidad and Tobago	HIC	1,390,000	0.204	283,560	2.8	18		982	16	984	12	988	5	1.76329525	
Singapore	HIC	5,639,000	0.123	693,597	6.9	3		997	2	998	1	999	25	3.60439852	

Table 1 (continued)

Country	Income Bracket	Population	% Population < 15 yo	Population < 15 yo	2018 Pop Density per 100,000 (< 15 yo)	Child < 5 mortality (per 1000 live births)	Mean % Population < 15 yo	Child < 5 Survival Rate	Infant < 1 mortality (per 1000 live births)	Infant Survival Rate	Neonatal mortality (per 1000 live births)	Neonatal Survival Rate	Pediatric Surgeons	PSWD per 100,000 children	Median PSWD
Bahamas	HIC	385,650	0.225	86,771	0.9	10	18.7%	990	8	992	5	995	1	1.15245545	2.13

For each income bracket, the mean proportion of the population < 15 years old and the median PSWD were calculated. *LIC* low-income country, *L-MIC* low-middle income country, *UMIC* upper-middle income country, *HIC* high-income country, *Yo* years old, *PSWD* pediatric surgical workforce density

with PSWD less than 0.37 was 332,365,760. Currently, the 13 countries below the 0.37 PSWD threshold have a mean PSWD of 0.12 and a total of 583 pediatric surgeons, with two LICs having only one pediatric surgeon. Therefore, to reach a PSWD of 0.37, there would need to be an additional 1215 pediatric surgeons across the 13 countries included in this study.

Discussion

To our knowledge, this is the first study examining the correlation between PSWD and pediatric-specific mortality rates across a diverse sample of countries. Similar to the LCoGS's findings of maternal mortality correlating with surgical workforce density, PSWD has a strong correlation with pediatric-specific population-level mortality rates. A critical threshold of PSWD 0.37 per 100,000 children was associated with significant improvements in survival.

Although there are many non-surgical causes of maternal mortality, its strong correlation with surgical workforce density has created a benchmark for countries to target in increasing their specialist providers [7]. Through local tracking of the surgical workforce, countries can assess the impact of migration, retirement, geographic distribution, number of training positions and graduate retention on their surgical workforce density. Similarly, though there are many non-surgical causes of pediatric mortality, our results demonstrated the PSWD strongly correlated with neonatal, infant, and under 5 mortality. Rocha and colleagues also demonstrated that areas of increased surgical workforce density correlated with reduced childhood mortality, though the analysis was not specific to PSWD and was limited to Brazil only [11].

Correlating surgical workforce density with population-level mortality rates allows for establishing a critical threshold of workforce density associated with significant improvements in survival. In fact, the LCoGS identified a critical threshold of 20 surgeons, anesthesiologists, and obstetricians per 100,000 people is associated with significant increases in maternal survival, which has subsequently served as a benchmark for tracking progress toward global surgical access and a target for countries when developing national health strategies [12, 13]. Although studies have described the significant variability in pediatric surgeons around the world and the critical role they play in pediatric care, there are no previous studies of the specific PSWD threshold associated with improvements in childhood survival. Instead of using pediatric population-level mortality rates, Hamad and colleagues examined the threshold associated with improved surgical outcomes and found a PSWD of 0.4 per 100,000 children correlated with significant improvements in survival for children with gastroschisis, esophageal

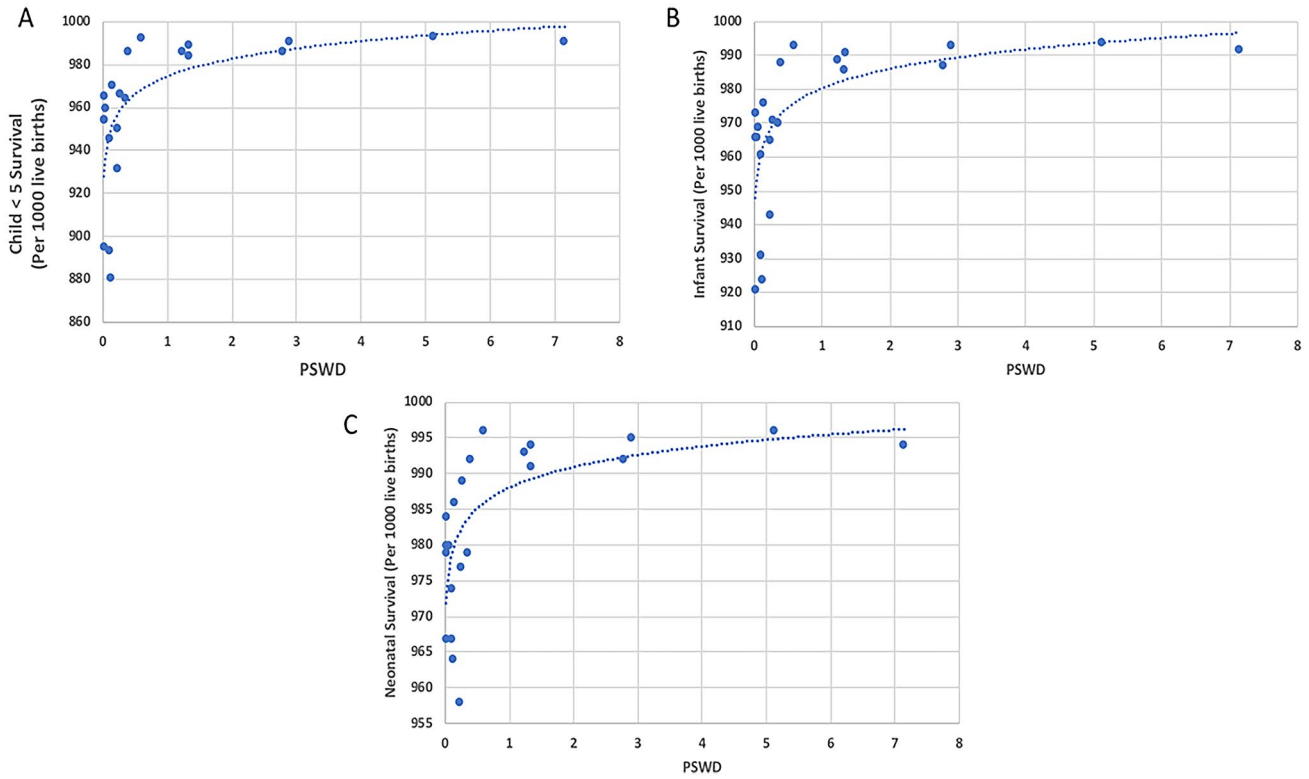

Fig. 1 Child < 5 years old (**A**), infant (**B**) and neonatal (**C**) survival rates plotted as a function of PSWD. *PSWD* pediatric surgical workforce density

Table 2 Spearman's calculation demonstrating the strength of correlation between neonatal, infant and under 5-year-old survival rates with PSWD

	Neonatal	Infant	Child < 5
Spearman correlation coefficient	0.78 ($p < 0.001$)	0.82 ($p < 0.001$)	0.83 ($p < 0.001$)
Critical PSWD threshold (per 100,000 children)	0.37	0.37	0.37

The critical PSWD threshold that correlated with significant gains in survival for each mortality curve is also displayed

atresia, intestinal atresia and typhoid perforation [9]. The authors argued this PSWD of 0.4 established a novel benchmark for the scale-up of the pediatric surgical workforce [9]. In comparing PSWD with pediatric population-level mortality rates, we demonstrated a PSWD of 0.37 correlated with significant improvements in childhood survival. Therefore, a PSWD of 0.37–0.4 per 100,000 children is associated with not only improved outcomes for surgical conditions, but also increased pediatric survival across the population [9]. This PSWD threshold could serve as a goal/metric in national surgical, obstetric and anesthetic planning (NSOAP), where a diverse group of medical and government stakeholders work to identify a country's urgent health needs and strategically allocate resources accordingly [7, 8].

Unfortunately, all LMICs (and one UMIC) sampled were below the critical threshold PSWD of 0.37, representing 332 million children with inadequate access to surgical care. This PSWD deficit is especially critical in LMICs, where a greater proportion of the population is less than 15 years old and there are higher birth rates, with a greater prevalence of complex, congenital conditions [13, 14]. Thus, many children will continue to die from treatable conditions if this deficit is not addressed. Additionally, pediatric patients often require specialized anesthesia care; thus, its availability may be a rate-limiting step to providing surgical care, even with available surgical providers [15]. Currently, efforts are underway to increase the PSWD through targeted training programs such as the collaboration between the College of Surgeons of East, Central, and South Africa (COSECSA), the West African College of Surgeons (WACS), and KidsOR—a charitable organization working to build surgical infrastructure in LMICs [16, 17]. These programs aim to

support the development of 120 centers of excellence in pediatric surgical care across Africa, including training pediatric surgeons, anesthesiologists, nurses, and surgical technicians and providing high quality, pediatric-specific operating theatres [18].

Additional strategies have included task shifting to other surgeons, physicians or surgical technicians, when appropriate [15, 17]. A common practice in most countries, general surgeons frequently provide non-complex pediatric surgical care with equivalent outcomes; and while they are not a substitute for pediatric surgeons for complex and congenital conditions, they provide critical and timely surgical care, especially in rural regions [19]. The Global Initiative for Children's Surgery outlined the optimal resources, infrastructure and personnel needed to provide pediatric surgical care specific to each condition [16, 18]. Initiatives to provide training for local providers at district hospitals, who are often the first point of contact for children with surgical problems, have been successfully implemented around the globe. For example, trauma training for non-specialist providers in low-resource settings in sub-Saharan Africa demonstrated significant improvements in knowledge and clinical confidence [16]. Meanwhile, in India, successful training and support initiatives were implemented to instruct rural providers on basic perioperative pediatric orthopedic, general surgery and anesthesia care [20]. Many LMICs have also demonstrated success in increasing surgical volume and access through training surgical technicians to independently perform basic surgical procedures, maintaining high-quality outcomes with faster and less costly training than specialist surgeons, though no studies exist on whether this is applicable to pediatric surgical conditions [9, 21]. While this strategy does not eliminate the need for pediatric surgeons for complex and congenital conditions, it may increase surgical accessibility for children with basic surgical needs and provide relief to an overburdened and limited pediatric surgical workforce. Whether through these existing efforts or emerging initiatives, there is an urgent need to increase the pediatric surgical workforce to meet the United Nations' SDG 3.2, to significantly reduce childhood mortality [5, 8].

While this study offers a novel assessment of the correlation between PSWD and pediatric population-level mortality rates, there are some notable limitations. First, the sample was limited to 26 countries that provide publicly available and subspecialty-specific licensing data. Although the sample was geographically and economically diverse, this sample may not be representative of the PSWD in other countries with similar resources. Second, in some countries, we were unable to determine if providers practice year-round in country or are retired; however, the majority of countries provide annual information on whether the license is active, suggesting the number of retired surgeons inadvertently included was very low. Third, many other providers besides pediatric surgeons provide surgical care to children, including general surgeons, other specialist surgeons (neurosurgeons, orthopedic surgeons, urologists, plastic surgeons, etc.) and other physicians or surgical technicians. Using licensing data alone, one cannot determine the number of non-surgical physicians or other providers who deliver surgical care in a given country. While these providers do provide important care, our focus was on pediatric surgeons specifically, as they are critical to providing comprehensive care for complex and congenital conditions. Finally, this study was limited to a retrospective analysis; a prospective study would be more useful to clearly identify the number of currently practicing pediatric surgeons in each country and the impact of unforeseen circumstances, such as the added stress from canceled surgeries during the COVID-19 pandemic to already overburdened health systems in LMICs.

Future analyses should increase the sample size of countries analyzed and prospectively assess the impact of interventions to increase the PSWD in LMICs. Additionally, research is needed to assess the correlation of pediatric population-level mortality rates with pediatric anesthesia workforce density, as they are critical to providing successful surgical care for children. Finally, it will be important to prospectively assess the impact of increased PSWD in LMICs on surgical volume, surgical outcomes and overall childhood survival. PSWD is only one indicator of surgical access and is almost certainly an indirect representation of other resources, infrastructure, and specialists needed for comprehensive pediatric care such as intensive care, anesthesiology, nursing and advanced nutritional support. Nevertheless, pediatric surgeons remain an essential component of a functional health system and PSWD can serve as a target for national health planning.

Conclusion

PSWD correlates with population mortality rates for neonates, infants and children under 5 years' old, with a critical threshold of 0.37 PSWD associated with a significant increase in survival. These novel findings suggest the current PSWD in LMICs, where a greater proportion of the population is less than 15 years old, have a higher birth rate, and have a greater prevalence of complex and congenital surgical conditions, is inadequate to meet the UN SDG 3.2 for infant and under 5 mortality. To improve the overall survival of children globally, further efforts are needed to increase the training and retention of pediatric surgeons in LMICs and to expand the associated health workforce, infrastructure, and services needed to care for infants and children with surgical conditions.

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Declarations

Conflict of interest The authors have no conflicts of interest relevant to this work to disclose.

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